State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES
Northern District

SAN JOAQUIN RIVER TRIBUTARIES

SPAWNING GRAVEL ASSESSMENT

STANISLAUS, TUOLUMNE, MERCED RIVERS

NOVEMBER 1994

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FOREWORD

The Stanislaus, Tuolumne and Merced Rivers support a natural run of chinook salmon which return from the Pacific Ocean via San Francisco Bay, the Sacramento/San Joaquin Delta and the San Joaquin River. Since the 1940s, Chinook salmon production has declined by over 85 percent in the San Joaquin River drainage (Low, 1993).

In 1988, with the passage of the Salmon, Steelhead, Trout and Anadromous Fisheries Program Act, the California Legislature mandated that the Department of Fish and Game (DFG) restore depleted salmon, steelhead, trout and anadromous fish stocks statewide. The Legislature decreed that the policy of the State is to increase the natural production of salmon and steelhead trout by the end of the twentieth century. The Legislature thereby directed that the DFG develop a plan and a program to double the current natural production of salmon and steelhead resources (Low, 1993).

Restoration of salmon spawning and rearing habitat is a major part of the DFG program. A critical factor affecting the development and survival of salmonid eggs and alevins is size distribution of spawning gravel. The distribution of spawning gravel in the San Joaquin River tributaries is altered by dams, streamflow diversions, and mining. Dams eliminate both the delivery of spawning-size gravel from upstream sources and the necessary high flows which flush clogging sediments from spawning areas. Diversions and low flows have caused formation of sandbars which reduce available spawning area. Aggregate mining, instream and offstream, have locally eliminated suitable spawning gravel from the channel (Low, 1993).

PART I: INTRODUCTION

PURPOSE AND SCOPE

This report documents the spawning gravel quality and quantity in the lower Stanislaus, Tuolumne and Merced Rivers, about 55 river miles of the San Joaquin basin. The study areas and surrounding cities are shown in Figure 1. Figure 2 shows the study reaches of each river. The study reaches are:

- Lower Stanislaus River from Goodwin Dam to Riverbank.
- Lower Tuolumne River from La Grange Dam to Waterford.
- Lower Merced River from Crocker-Huffman Dam to Cressey.

The reaches range from approximately 20 to 25 miles in length. They begin immediately downstream of large dams where the rivers emerge from Sierra Nevada foothills onto the San Joaquin Valley floor. In the foothills, the rivers flow through steep-walled canyons incised into uplifted volcanic, sedimentary or metamorphic rocks. Where these rivers empty onto the valley marks a gradient inflection from relatively steep gradients in the foothills to gentle gradients on the valley floor.

Riffles and river miles, such as those in Figure 2, are plotted in detailed river atlases by the Department of Fish and Game. The riffle or river mile numbers plotted in Figure 2 are selected as general reference points. Riffle numbers are plotted on the Merced River map in lieu of river miles.

Field work consisted of bulk and surface gravel sampling and spawning gravel area measurement. Bulk gravel samples were taken at 51 salmon spawning riffles. Surface samples were taken at 59 riffles.

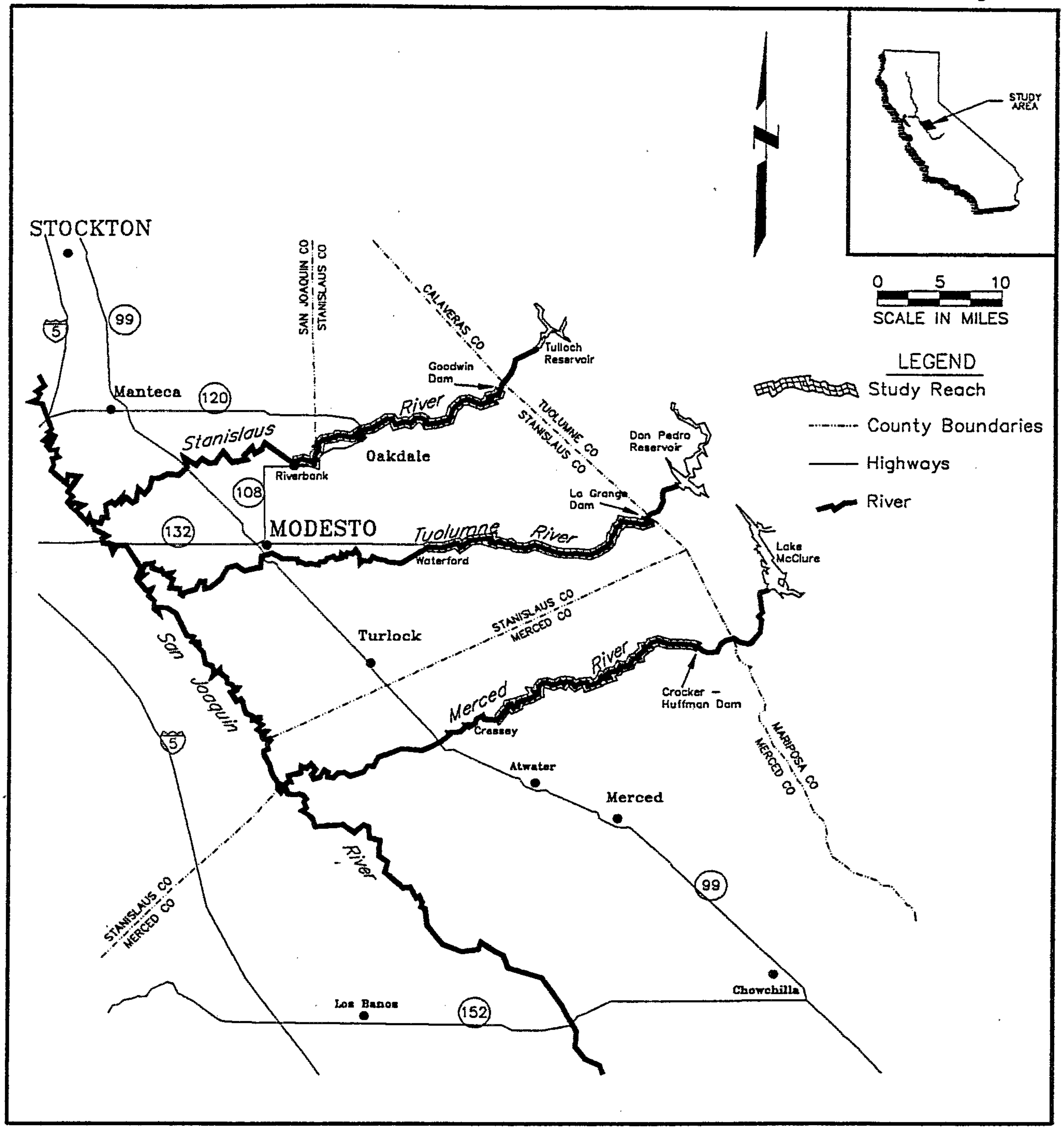
Bulk and surface sampling data are statistically reduced to represent surface and substrate size composition. Size composition is presented as percent by weight which is customary in spawning gravel assessment (Young et al, 1991).

Spawning gravel area is measured in square feet. The measurements were performed at riffles with preferred spawning areas during typically available spawning flows.

REPORT ORGANIZATION

Part II of this memorandum discusses factors pertinent to spawning gravel. A discussion of field sampling methodology and gravel resource assessment is in Part III. Part IV provides an assessment of the spawning gravel resources on the three study reaches. Part V is a description

Figure 1



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STUDY AREA LOCATION MAP

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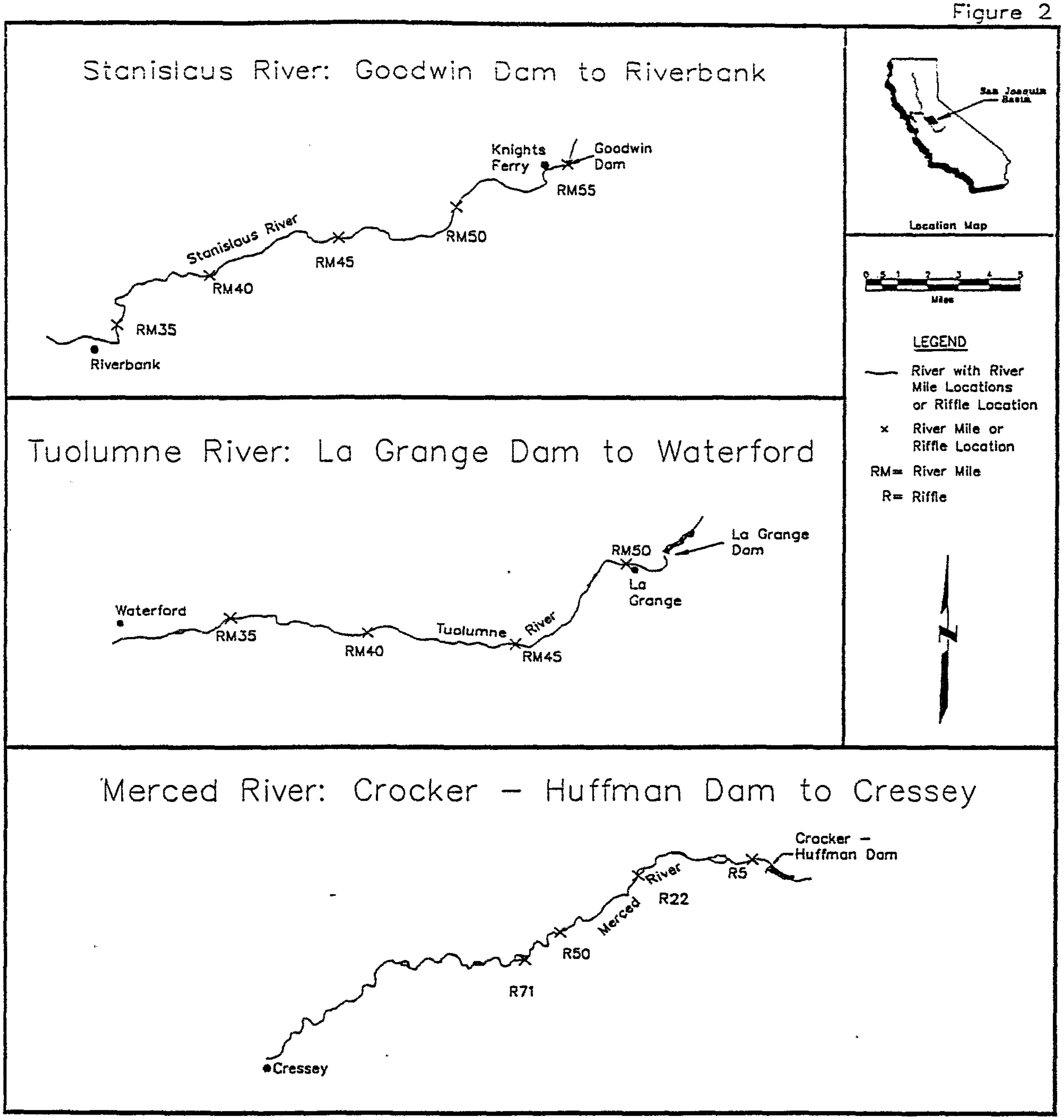
Figure 2



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San Joaquin River Tributaries
Spawning Gravel Assessment
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STUDY REACHES WITH SELECTED
RIVER MILES OR RIFFLE NUMBERS

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of river conditions. Mechanical gradation curves, Wolman curves, and raw-data spreadsheets are contained in Appendices A,B,C and D. Appendix E contains maps of selected riffles on the Tuolumne River

PREVIOUS STUDIES

The Department of Water Resources has participated in enhancement projects on the San Joaquin tributaries as mitigation for the Four Pumps Agreement (Landis, 1993). The sites which have been enhanced under the Four Pumps Agreement include Merced River riffles 1B, 2C, and 7B near Crocker-Huffman Dam. Gravel was trucked into these sites and deposited into the river to enhance these riffles. The Department participated in other enhancement projects including mitigation work at Ruddy Gravel Mining Plant on the Tuolumne River. Gravel was not imported to this site, however the river channel and banks were reworked extensively.

On the Tuolumne River, riffles enhanced under the Davis-Grunsky Act include most of the riffles from La Grange to Riffle 7.

Earth Analysts Science and Engineering (EA) performed studies on the Tuolumne River for the Turlock Irrigation District and the Modesto Irrigation District. EA work included field survival to emergence tests, a superimposition (redd-on-redd encroachment) study, experimental gravel cleaning, and spawning gravel area delineation on the Tuolumne River. EA delineated spawning habitat defining the entire areal extent of the riffles. Conclusions from the EA study include the finding that extensive superimposition of redds decreases egg survival. EA also concluded that the average egg survival to alevin emergence rate on the Tuolumne River is thirty four percent (Earth Analysts Science and Engineering, 1992).

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The Stanislaus, Tuolumne, and Merced Rivers, in the reaches extending from the base of the foothills to approximately 20 miles downstream, are altered by large upstream dams. These dams were constructed in the early decades of the twentieth century and have largely trapped gravel transport and high-discharge snowmelt flows in the spring and early summer. Without gravel transport, spawning areas downstream of these dams receive no new gravel. Without high snowmelt flows in spring which flush fine sediment from riffles, sediment accumulation on the riffles occurs. Sediment accumulation allows encroachment of perennial aquatic grass onto existing riffles, thereby effectively reducing area available for salmon spawning.

The Department of Water Resources analyzed the particle size composition of selected riffles identified by DFG. The gravel and sediment composition of the analyzed riffles is plotted as gradation curves in Appendix A and as bulk mass by size range in Appendices B and C. Appendix D contains values for the combined surface and subsurface bulk analysis.

The following are conclusions and recommendations resulting from the investigation:

1) The analyzed riffle gravel generally are sufficiently coarse for salmon spawning. The range of suitability varies from riffle to riffle.

2) On many riffles, particularly on the Stanislaus River and to a lesser extent on the Tuolumne River, the sand-sized particle content is generally greater than that which is considered optimal for spawning and rearing habitat. The higher sand content of several analyzed riffles may cause egg or alevin mortality rates greater than experienced on coarser, more ideal gravel.

3) The mean diameters of sand-sized particles on the Stanislaus River appear appreciably smaller than the mean diameter of sand from riffles on the Tuolumne or Merced Rivers.

4) Vegetation is encroaching on riffles in absence of sufficient spring flushing flows. The encroachment of vegetation in the active channel, particularly perennial aquatic grass, is most pronounced in riffles on the Tuolumne River. We recommend the removal or abatement of vegetation to improve spawning habitat. Vegetation should be monitored to assess its rate of encroachment.

5) To increase permeability through sand-laden riffles, particularly on the Stanislaus River, opening of the gravel is recommended. A bulldozer with ripper bars is effective for opening up riffles.

6) Gradation curves for riffles on the Stanislaus River downstream of mined areas indicate an increase in the percent of sand. The apparently greater percentage of sand in these riffles may be the result of upstream gravel mining. We recommend that a study be performed to determine the amount of sand (if any) contributed by mining above River Mile 50 before the recommendation to rip downstream riffles is implemented.

7) On the sections of each river immediately downstream of the dams, water temperatures are sufficiently cool for salmon spawning yet the gravel is excessively coarse for suitable habitat. Therefore, to match suitable water temperature with suitable gravel, import and emplacement of properly graded gravel along riverbanks along these reaches is recommended.

PART II: CHINOOK SALMON AND SPAWNING GRAVEL

CHINOOK & SALMON SPAWNING GRAVEL

Fall-run chinook salmon support the bulk of the ocean salmon fishery and constitute over ninety percent of the salmon population in the Central Valley (Earth Analysts Science and Engineering, 1992). The adults of the fall run arrive in the Sacramento - San Joaquin Delta in early fall as the water begins to cool and the flows begin to increase. Most of the fish enter the San Joaquin and Sacramento rivers between early September and early December. Peak spawning occurs in November and December, soon after the fish have reached the spawning riffles.

Spawning gravel is a mixture of sand, gravel and cobbles which is sorted by the female salmon during spawning. The average gravel size must be small enough for the female to dig a nest, or redd, with her tail. The spaces between particles must be sufficiently large to accept the fertilized eggs. The percentage of fines (sand, silt and clay) must be low (approximately 5 percent or less) to allow the flow of oxygenated water through the redd and to prevent the gravel from becoming compacted. Hydrologic variables such as water depth, velocity, and temperature must be correct before salmon will spawn. Unsuitable gravel reduces egg and alevin survival. Spawning chinook salmon prefer the following conditions:

1) Gravel size ranging from 1/2 to 4 inches in diameter (Thompson, 1972).

2) A water depth of ranging from 9 inches to 3.5 feet (Bell, 1986).

3) Water velocities ranging from 1.5 to 3 feet per second (Thompson, 1972).

4) Water temperatures ranging from 5.6 to 13.9° C for spawning and 5.0 to 14.4° C for incubation (Bell, 1986).

5) Downwelling of water through the gravel (Meehan, 1991).

6) Resting pools and shade (California Department of Fish and Game, 1980).

7) Gravel depth of 18 to 30 inches (California Department of Fish and Game, 1980).

Figure 3 shows the general character of a river gravel bed. The most typical feature of a gravel river bed is a surface cover which is relatively coarse in comparison to the underlying substrate (Church, et al 1987).

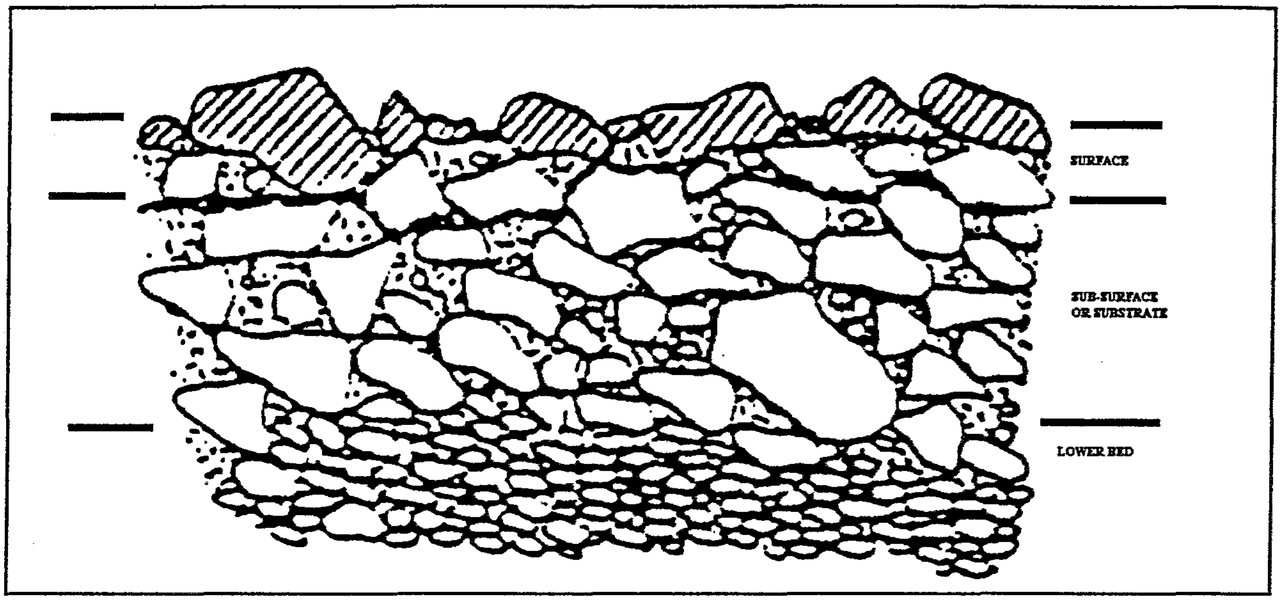

Figure 3. River Gravel Bed Depicting Surface and Substrate Layers. Adapted from Church et al, 1987.

The Redd

The female salmon may require as many as seven days to complete a nest, or redd. The female digs a hole in the gravel and deposits eggs that are subsequently fertilized by the male. The eggs are covered as the spawning fish digs in the adjacent upstream gravel. A number of egg pockets, usually no more than ten, are created along the center-line of the redd, which is aligned in the direction of the flow. A pit is left at the upstream end of the redd where the gravel covering the last egg pocket was excavated, and a crest is created at the downstream end, behind the point where the first egg pocket was buried. The region from the back of the pit to the crest, referred to as the mound, is the site of the egg pockets. The shape of the redd is approximately ovoid (Earth Analysts Science and Engineering, 1992).

The size of the redd is proportional to the size of the spawning female: a cross-sectional area parallel to the thalweg may be as large as 18 square feet. (12 feet long and 1.5 feet deep). For fall run chinook of average 25 pound size, average surface area of a redd is about 55 square feet (Bell, 1986). Figure 4 shows a profile and top-view of a typical salmon redd.

Redd construction effectively cleans the subsurface or substrate of the very fine materials and yields gravel with high permeability. However, land uses such as logging, road construction, overgrazing and in-stream mining can cause increased sedimentation in the interstices of the spawning gravel, reducing the permeability of the substrate and percolation of water to the developing eggs. Increased egg mortality results from the clogging of pores in the spawning gravel.

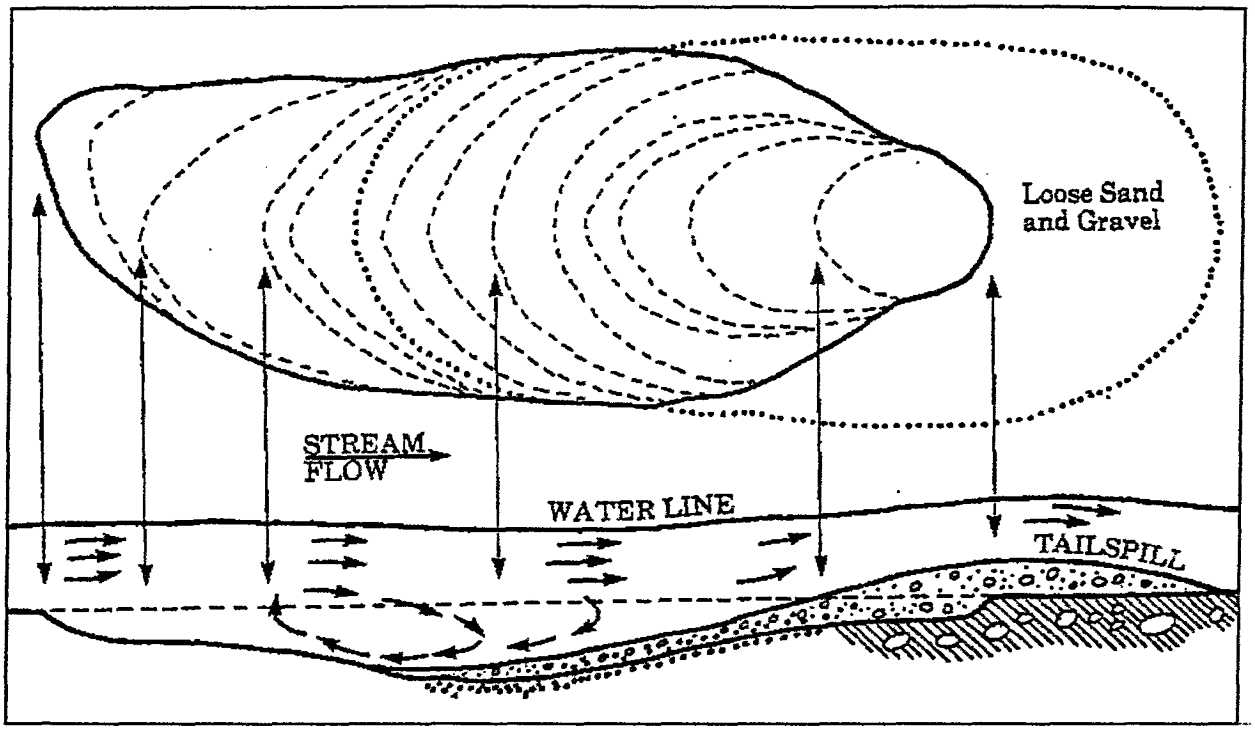

Figure 4. Profile and Top View of a Salmon Redd. Nest-building by the female cleans the gravel, increasing permeability. Adapted from Bell, 1986.

Redd Location

Salmonids prefer to spawn in the transitional area between pools and riffles where flow velocity increases (California Department of Fish and Game, 1953). DWR (1984) observed that the chinook salmon in the Sacramento River prefer to spawn at the head of riffles located near point bars.

By placing a tracer (crystals of potassium permanganate) on the gravel surface, Stuart (1953) demonstrated the presence of downwelling currents in the transitional areas between pools and riffles. Stuart noted that the gravel in the transition area was easy to excavate and relatively free of silt and debris. Vaux (1962) reported that downwelling currents normally occurred in areas where the streambed was convex, such as the pool-riffle transition, and upwelling currents occurred in the concave areas, such as the downstream end of a riffle.

Figure 5 depicts typical longitudinal sections of a preferred spawning area. Section A depicts convexity of the substrate at the pool-riffle transition which induces downwelling of water into the gravel. The area likely to be used for spawning is marked with an X. Section B depicts redd construction which results in negligible currents in the pit (facilitating egg deposition) and increased currents over and through (downwelling) the tailspill. Section C depicts further excavation and egg-covering which results in the extension of the pit upstream, which may also be used for spawning. Increased permeability and the convexity of the tailspill substrate induces downwelling of water into the gravel, creating a current which flows past the eggs. The current brings oxygen to the eggs and removes metabolic products.

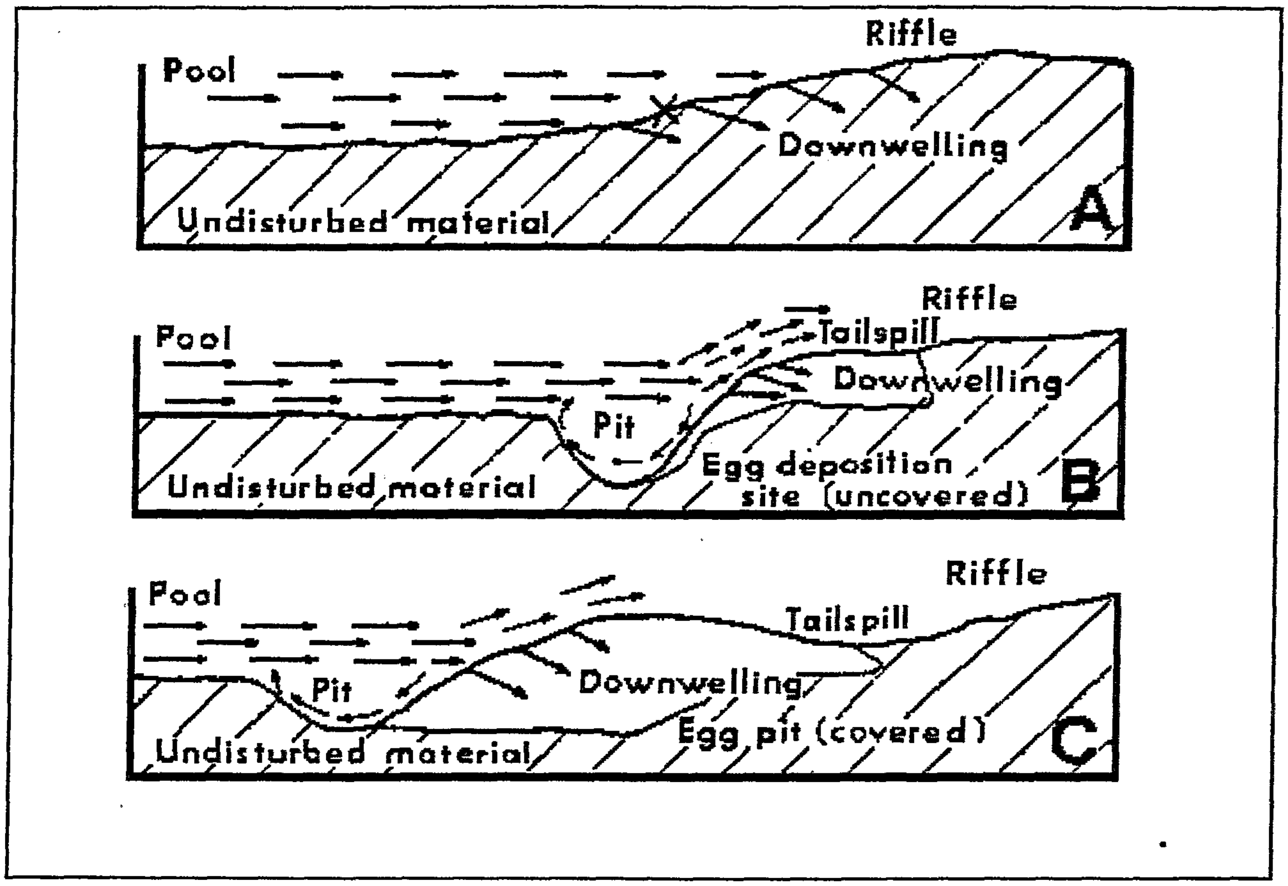

Figure 5. Longitudinal Sections of a Spawning Area. Adapted from Meehan, 1991.

After the eggs have been deposited, the female remains on the nest, defending the redd from other females who might attempt digging in the gravel, thereby killing her eggs. Soon after spawning, the male and female adult salmon die. Superimposition of later spawners digging on the pre-existing redds is a cause of egg mortality (Earth Analysts Science and Engineering, 1992).

Incubation and Emergence

The salmon eggs hatch at least 45 days after spawning. The hatched eggs are called alevins (young fish with yolk sac) which remain in the gravel for upwards of 45 days (Mih, 1978). The alevins live in a layer about 12 inches thick beneath the surface of the streambed, feeding on their yolk sac and, to a lesser degree, on organic materials which are filtered by intragravel water flow. Intragravel water flow also removes metabolic products and supplies sufficient dissolved oxygen.

The alevins emerge from the gravel as fry or juveniles when they are about 1.25 to 1.5 inches long. Most of the fry remain in the river to rear for a few months prior to emigrating to the ocean in late spring. They spend much of their first month along shallow stream margins in slow water, hiding in gravel and cobbles from predators. The fry gradually move to water with higher velocities as they grow.

As the fry grow, they become adapted to seawater by smolting. Smolting is the physiological transformation of juveniles into smolts that allows them to survive in seawater. The smolts then migrate downstream to the estuary. Migration in the San Joaquin River basin peaks around early May (Earth Analysts Science and Engineering, 1992). During this time, olfactory imprinting of the juveniles of the natal stream occurs. Olfactory imprinting guides the fish back to their native tributary.

DISCUSSION OF SPAWNING GRAVEL SUITABILITY

A single, unified standard for describing the suitability of salmon spawning gravel is not established. No single variable can adequately describe overall spawning gravel quality, and single-variable descriptors should be avoided (Kondolf 1993). This discussion examines several researchers' results and presents a range of suitable gravel dimensions which incorporates their recommendations. Dimensions are recorded in metric units for smaller fractions and English units for coarser fractions (see unit conversion on inside of rear cover).

Grading of Gravel for Suitability Analysis

The grading of a gravel is the distribution of particle sizes. Grading is determined by separating a representative sample of the gravel into size groups through sieves.

Conforming to Unified Soil Classification System (USCS) nomenclature, fine grains pass a Number 200 mesh sieve (0.074 mm). Coarse grains are larger than a Number 200 mesh sieve. Coarse grains are divided into, in ascending order, sand, gravel, and cobbles. Cobbles range from 3 inches to 12 inches in diameter. Gravel ranges from a number 4 sieve to (4.75 mm) to 3 inches. The USCS defines sand as smaller than a number 4 sieve (4.75 mm) and larger than a number 200 sieve (0.074 mm).

Fine grains or fines are smaller than the Number 200 sieve and are of three types: silt, clay, and highly organic soils. Size distinction is not made between silt and clay in the Unified Soil Classification System; rather, the two materials are differentiated by low (silt) or high (clay) plasticity (Spangler and Handy 1982).

Synopses of Spawning Gravel Suitability Investigations

Several researchers have investigated the size range or dimensions of gravels suitable for salmon spawning. The following synopses of research are presented to convey the general results of investigations.

Shirazi et al (1981) observed that a ratio of gravel diameter (Dg) to egg diameter (De) provides a strong correlation with embryo survival. Figure 6 shows that egg to alevin survival

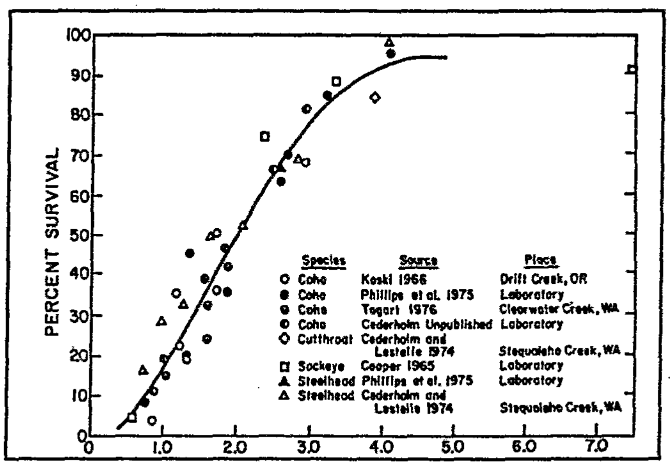

Figure 6. Relationship Between Embryo Survival (Y axis) and Dg/De Ratio (X axis). Adapted from Shirazi et al, 1981.

increases as the Dg/De ratio in redds increases. Maximum survival occurs with a ratio approaching 4. Chinook egg diameters range from 6.3 to 7.9 mm which indicates that maximum survival occurs in redds with a Dg above 25 mm.

The permeability of the substrate surrounding the eggs in part determines the rate and volume of water flowing through the redd. Substrate permeability is a critical factor in egg and alevin survival because: (1) dissolved oxygen is brought to the developing eggs via water flowing through the redd; and (2) metabolic wastes are removed from the developing eggs by the flowing water (Bell 1986).

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Permeability is considered high by McNeil and Ahnell (1964) when the bottom materials contain less than 5 percent by volume of particles passing through a sieve opening dimension of 0.8 mm. According to McNeil and Ahnell, if the volume of particles passing the 0.8 mm aperture exceeds fifteen percent, permeability is low.

Particle sizes that reduce embryo survival and impede emergence have been defined as those less than 6.4 mm (0.25 inch) (Bjornn and Reiser, 1991). According to Kondolf (1993), sediment particles less than 1mm (medium sand) will reduce the permeability of spawning gravel. Kondolf adds that the gravel must be free of interstitial sediment less than 3 mm (coarse sand) that would prevent fry emergence.

Hinton and Puckett (1974) published a dimensions of acceptable spawning gravel sizes based on percent by volume shown in Table I. The size range and volume of gravel was based on samples taken from king salmon redds in the Eel River.

TABLE I
Suitable Spawning Gravel for Chinook Salmon

CENTIMETERS	GRAVEL SIZE (INCHES)	PERCENT BY VOLUME
15.2 to 30.5	6 to 12	30 or less
7.6 to 15.2	3 to 6	10 or more
2.5 to 7.6	1 to 3	50 or less
1.3 to 2.5	0.5 to 1	20 or less
0.4 to 1.3	0.16 to 0.5	20 or less
0.04 to 0.4	0.015 to 0.16	20 or less

Source: Hinton and Puckett, 1974.

According to Bjornn and Reiser (1991), upwards of 20% of the particles can be less than 6.35 mm in diameter without significantly reducing embryo survival. The effect of fine sediment on fry emergence is shown in Figure 7.

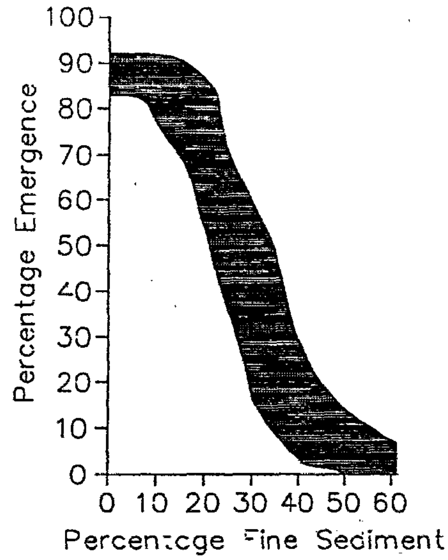

Figure 7. Fine Sediment vs Fry Emergence. The stippled area is a range of percentage fry emergence as a function of percentage of fine sediment in a redd. Adapted from Bjornn and Reiser, 1991.

The particle sizes shaded on the gradation curves in Appendix A represent acceptable spawning gravel. These sizes account for recent studies on survival to emergence in salmon redds: the upper portion of the curve follows the lognormal distribution of Shirazi et al (1981), the lower portion of the curve uses the maximum acceptable fines as described by Ahnell (1964) and Bjornn and Reiser (1991).

PART III: SPAWNING GRAVEL SAMPLING METHODOLOGY

INTRODUCTION

Spawning gravel samples were taken from June to November, 1993, during periods of low flow on the Stanislaus, Tuolumne and Merced Rivers. Discharge on each river during field sampling varied from 200 to 375 cubic feet per second (cfs).

A twelve-foot rubber raft was used to carry staff and equipment to sample sites. DFG, Fresno, provided riffle atlases and a written description of the rivers by river mile.

Riffles sampled on the Tuolumne River are identified by river mile and DFG riffle number. Two riffle sites on the Tuolumne had no DFG number designation because the sites were located in the Ruddy gravel rehabilitation area. These riffles are called Rudd1 and Rudd2. Rudd1 is located at the head of the riffle adjacent to the Ruddy mine on the right bank. Rudd2 is located at station 22 + 00 (right bank) on the Ruddy channel rehabilitation blueprints (Landis 1983).

Riffles sampled on the Stanislaus River are identified by river mile only.

Riffles sampled on the Merced river are identified by river mile and DFG riffle number. Two sampled riffles had no DFG number designation. These riffle sites are located in the Gallo Ranch, and are called Gall1 and Gall2, at river mile 35.9 and 39.6, respectively.

Three types of sampling methodology were used to characterize spawning gravel: bulk sampling, surface or Wolman sampling, and spawning gravel area measurement.

BULK SAMPLING

Bulk sampling is the collection of a large volume of stream gravel for analysis. The sample is subjected to mechanical analysis of the material by sieving which splits the material by size. The sieve results are plotted as gradation curves.

The bulk sampling method was used to analyze and characterize gravel size distribution at selected riffles. The bulk samples were analyzed in three categories: surface, subsurface, and combined surface and subsurface. Fifty one bulk samples were taken from riffles on the Stanislaus, Tuolumne, and Merced Rivers. Fewer riffles were sampled than anticipated due to high flows, vegetative encroachment, and coarse cobbles and substrate near the top of the reaches.

Three commonly used methods of bulk sampling are:

1) freeze core method
2) excavated core (McNeil Sampling)
3) sampling by shovel

Grost, Hubert and Wesche (1991) compared these methods for sample composition, cost and field efficiency. The methods were field-tested on substrate consisting primarily of materials smaller than 10 cm (0.4 inches) in diameter. Water depths ranged from 6 to 40 cm (0.2 to 1.5 inches), and mean water velocities ranged from 20 to 80 cm/s (0.06 to 0.25 ft/s). Test results indicated no significant differences between the excavated core and shovel samples for any size-fraction of particles.

Grost et al concluded that a shovel is a viable alternative to an excavated core sampler for sampling in streams less than 1.5 inches deep with water velocities less than 0.25 feet per second and a streambed consisting primarily of material smaller than 0.4 inches in diameter. Grost et al considered shovel sampling especially attractive for sampling in remote areas or when sampling budgets are limited.

DWR (1984) successfully used shovel sampling to assess spawning gravel on the Trinity, Feather and Sacramento Rivers. DWR collected dry samples at heads of point bars in these Northern California Rivers. DWR found shovel sampling useful when sampling large diameter and cobble size gravels. In the San Joaquin tributaries, DWR's sample collection technique was slightly modified for collecting samples instream.

In this investigation, sample gravel was collected with a shovel. The methods described by DWR (1984) were used in this investigation. Other sampling methods were evaluated and rejected because of the small size of the resulting sample or the time required to collect the sample.

While sampling instream with a shovel, the retention of fine particles is of paramount concern. To retain fines during sample extraction, the loaded shovel was kept horizontal and lifted to the water surface while maintaining a downstream velocity consistent with the current. The sample was then loaded into a five gallon bucket and carried to shore.

While sampling, only minor clouding of the water was observed, indicating that a minimal amount of fines were lost. Minor loss of sand was observed beneath the path of the shovel. The scattered sands were easy to identify because they were clean sands lying on darkened riverbed. Depending on the current velocity, upwards of 0.5 cups of sand size fraction was lost. Considering the size of our samples, the amount of sand and fines lost was insignificant. The shoveling technique described above worked well for gravel beds with current velocities up to 3 feet per second.

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Sample Location Selection

Sampling was limited to riffles with a shoreline sufficiently large to place the sieves on dry, level ground with room for two persons to operate. If two potential riffles were closely adjacent, the larger riffle was sampled because it provided more area for spawning.

After selecting a riffle, sample sites were consistently chosen at the head of the selected riffle because it is preferred for chinook salmon spawning. Velocities at sampling sites ranged from about 1 to 3 feet per second. Water depths ranged from 6 to 20 inches. Sample results are in Appendix B.

Sample Quantity

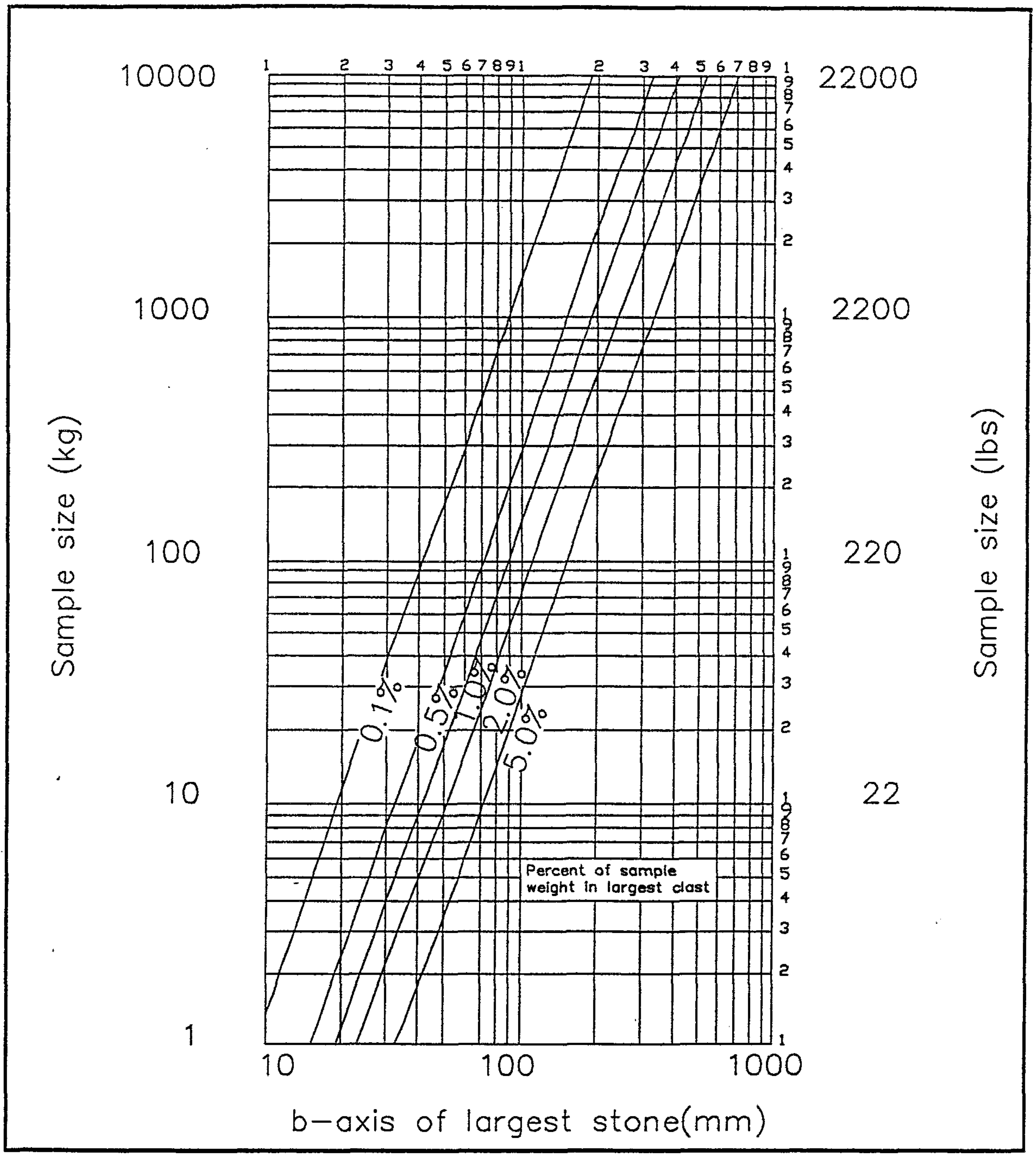
Sample quantity standards have been established, however the standards are inconsistent (Church et al, 1987). Church et al conducted several tests to determine requisite sample weight. The sample size criteria developed from the tests illustrated in Figure 8 show the variation in sample quantity as controlled by the size of the largest clast and the percentage of the sample that this size represents.

Sample quantity used in this investigation exceeded the criteria established by Church et al (1987). Figure 8 presents sampling quantity criteria based on the b axis of the largest clast and percent of sample weight in largest clast. Using Figure 8, the intercept of the b-axis dimension and the appropriate percent line is plotted. The Y-axis is the quantity in kilograms required for an adequate sample quantity. For example, a sample of the largest clast (comprising 0.5 percent of the sample weight) with a b-axis dimension of 100 mm would require a sample weight of 280 kg (620 lbs).

The surface dimension of the sample area was 2 feet normal to the current by 3 feet parallel to the current. The surface layer was collected and sampled separately from the substrate layer as previously discussed. For sample collection, the sampling extent of the surface layer is defined by the diameter of the largest particle, ranging from four to eight inches. Sampling depth of the surface layer did not exceed the diameter of the largest clast. The sampling extent of the substrate layer was determined by weight in pounds and typically extended to a depth of 12 to 16 inches.

Mechanical Analysis

Mechanical analysis is the separation of streambed material into graded size fractions by using sieves (Spangler and Handy 1982). The field sieves dimensions are two feet square. Sieve openings ranged from 3 inch to 3/8 inch. Laboratory sieves ranged from #4 mesh to #200 mesh. Table II lists the sieve sizes used in this investigation. The sieves were nested above a large plastic sheet formed into a basin to catch material smaller than the #4 mesh sieve for laboratory sieving. For sampling ease and safety, the sieves were placed on dry, level ground.



Adapted from Church et al,.1987

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San Joaquin River Tributaries
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BULK SAMPLE SIZE STANDARDS

TABLE II
Field and Laboratory Sieve Sizes

Field Sieves Inches or Mesh Number
3
1.50
0.75
0.375
Laboratory Sieves
#4
#8
#16
#30
#50
#100
#200

The samples gathered by shovel into the five-gallon buckets were unloaded onto the sieves. The sieves were shaken while being continually rinsed. Gravel particles over 6 inches in diameter were separated by hand using a ruler and weighed separately. Material retained on each sieve was weighed in a bucket on a hanging scale.

Particles passing through the #4 mesh sieve, retained by the plastic sheet, were drained into a bucket along with the rinsing water. The bucket was slowly drained of rinse water and the particles passing the #4 sieve were collected and weighed. About 10 to 14 pounds of the material from the catch bucket was weighed and saved for laboratory sieving.

Laboratory sieve sizes ranged from #4 mesh to #200 mesh. The sample material was thoroughly air dried and sieved with a mechanical shaker. The sample weight was corrected for moisture content. To prevent sieve clogging, a maximum of five to six pounds of material was sieved at a time. Material retained on each sieve was weighed on a balance scale and recorded on pre-prepared field data sheets.

Mechanical Analysis Graphs

Conventionally, mechanical analysis results are plotted on semi-logarithmic graphs (Figure 9), and are referred to as gradation curves or mechanical analysis graphs. Gradation curves graphically present the percentage of particles retained and passing through specific sieve apertures. The gradation curve in Figure 9 represents clast composition at a sample location on the Merced River. Appendix A contains gradation curves for all sampled riffles. The shaded area on the graph represents the acceptable range of spawning gravel sizes for chinook salmon. This range is discussed in Part IV in the section titled Bulk Sampling Data Analysis on page 23.

Along the X-axis, sieve aperture sizes are arranged in logarithmic succession. Sieve numbers are arranged along the upper X axis. The sieve numbers refer to the nominal number of openings per inch: a #4 mesh sieve means that there are 4 openings per inch, a #200 mesh sieve has 200 openings per inch. The aperture dimensions (millimeters) corresponding to each sieve size may be read directly on the lower X-axis. Hence, a #4 mesh sieve corresponds to an aperture dimension of 5.5 millimeters.

The arithmetic Y-axis is divided into percentage values of retained weight plotted along the right side of the graph and percent passing weight plotted on the left side of the graph. These inversely related percentages are dependent on the size distribution of the particles.

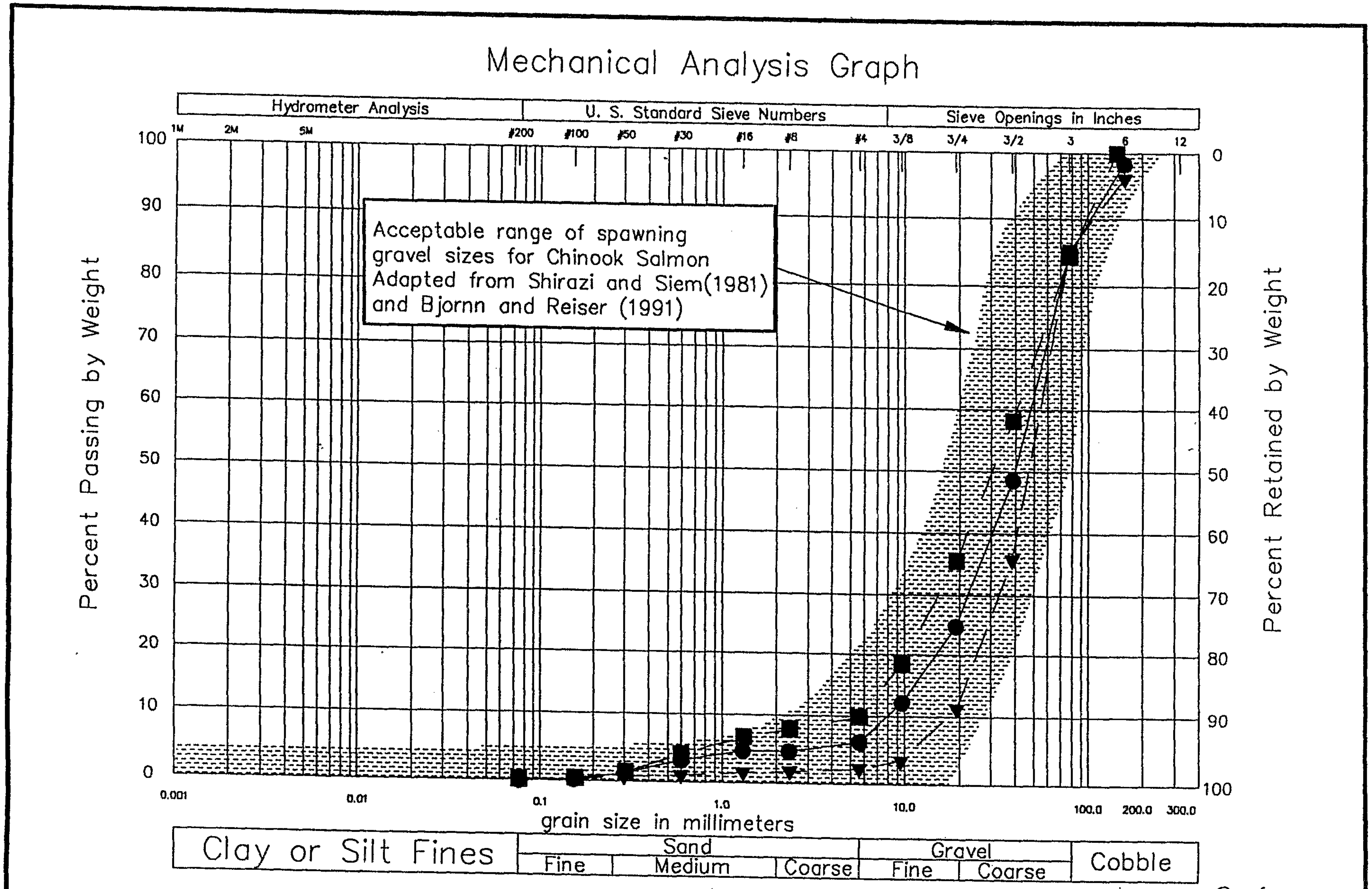
When the sieve analyses are plotted, the resultant curve will yield the percent passing (or inversely, percent retained) as a function of the aperture dimension and size range of the soil or gravel clasts. The shape and location of a gradation curve shows the general grading characteristics of a soil or gravel. A very steep curve, with no tail, indicates a relatively uniform soil or gravel with a small range of particle sizes. Conversely, a gentle curve indicates that a wide range of particle sizes exist. The gradation curves in Figure 9 represent a relatively well-mixed assortment of river clasts. Three curves are plotted on the graph in Figure 9: surface clasts, substrate clasts, and combined surface and substrate clasts. These curves are discussed in Part IV.

The median grain size, D_{50} is defined as the 50 percentile size, or the size which divides the distribution such that 50% of the sample by weight is finer and 50% is coarser than this size. The median can be easily read from the 50% line in a particle-size gradation curve. However, it indicates little about the range or skewness in particle sizes.

SURFACE SAMPLING

Surface samples were taken at 59 riffles using a modified Wolman method discussed below. Twenty samples were taken on the Tuolumne, twenty-two samples were taken on the Stanislaus, and seventeen samples were taken on the Merced.

The sampling method used to analyze and characterize stream-bed surface material at selected riffles was adapted from the grid method described by Wolman (1954). The Wolman method,



MECHANICAL ANALYSIS OF GRAVEL

MERCED RIVER RIFFLE GALL1

SAN JOAQUIN RIVER BASIN SPAWNING GRAVEL ANALYSIS

Figure 9

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with minor variation, was selected because of its relative simplicity and common usage. These attributes are beneficial in conducting field work under constrained conditions.

This method requires that individual stones be measured on the intermediate or b-axis by ruler or calipers, or classified using square openings in a template. The distance between successively sampled clasts is significant because of the propensity for clasts of similar size to imbricate. To reduce serial correlation in the sample, the sample grid should be chosen so that successively selected clasts are at least several grain diameters apart (Church et al 1987). This was accomplished by the sampler taking a step between each sample point.

By statistical analysis on logarithmically transformed data, samples as small as forty clasts are sufficient to yield consistent estimates of mean size. Wolman used 60 clasts in one demonstration of the method, although he recommended a 100-clast sample as used in this investigation.

To perform the Wolman method, one person paced along the head of the riffle. After each pace, the person closed their eyes and reached into the water with a pointed finger. The first particle touched was picked up and the particle's b-axis measured and recorded on the Wolman data sheet. The sampling person paced across the riffle head until water depth or velocity made sampling impossible or a shoreline was reached. Then the sampler took a pace upstream to begin sampling in the other direction along a parallel grid line. This was continued until 100 samples were recorded. The b-axis measurement was taken with a ruler scaled in phi units, with phi = $-\log_2$ of the b-axis diameter in millimeters.

PREFERRED SPAWNING GRAVEL AREA MEASUREMENT

Although not strictly a sampling method, this procedure for measuring the area of preferred spawning areas is included in the sampling methodology section. Preferred spawning gravel area was measured at 53 Tuolumne riffles, 65 Stanislaus riffles and 18 Merced riffles. The preferred spawning area is defined as the head of a riffle where flow ranges from one to three feet per second and gravel is not compacted. Under these conditions, egg and alevin survival rates are highest.

These measurements represent the most ideal, preferred spawning gravel. Salmon will likely spawn in other areas not included in these measurements. The measured area extends downstream to segments of the riffle where vegetative encroachment, stream flow velocity, or observed gravel dimension are insufficient to provide a preferred spawning area. The width of the preferred area was measured shoreline to shoreline. The length of the preferred area was measured from the riffle head upstream. Measurements were taken with a 150 foot nylon tape.

PART IV: SPAWNING GRAVEL RESOURCE ASSESSMENT

BULK SAMPLING DATA ANALYSIS

To analyze the bulk sample data, the percent weight passing each sieve was plotted as a gradation curve on a semi-log graph for each riffle. The surface, substrate, and combined surface and substrate gradations were plotted (Appendix A). Percentile diameters were read from the combined curve.

The gradation curves are presented in relation to an envelope of acceptable spawning gravel size ranges. The envelope is represented as a shaded area on each particle accumulation curve. The envelope was generated using data from Shirazi and Seim (1981) and Bjornn and Reiser (1991).

The bulk sampling data were analyzed in three distinct elements: the surface sample, the substrate sample and a combination of both surface and substrate samples were plotted as gradation curves for each riffle (Appendix A). The surface and substrate samples were added together on the combined spreadsheets in Appendix B. Appendix C contains spreadsheets for separate surface and subsurface samples. The combined spreadsheets present aspects of central tendency including geometric mean diameter (D_g), graphic geometric mean diameter (D_{gg}), standard deviation, skewness and kurtosis. Percent fines are also computed and presented with the combined surface and substrate spreadsheets in Appendix B.

The mechanical analysis spreadsheets in Appendices B and C convert the size fraction weights into size fraction percent by weight. Because only a representative amount of particles passing the #4 field sieve was retained for laboratory sieving, the spreadsheet calculates the percent moisture content of the laboratory sample, and proportionally distributes the adjusted weight among the size fractions. The spreadsheets in Appendix B contains particle dimensions at the D_{95}, D_{84}, D_{75}, D_{50}, D_{25}, D_{16}, and D_5. These dimensions are based on standard deviation increments: the D_{84} and D_{16} dimensions fall one standard deviation on either side of the median (D_{50}) and the D_{95} and D_5 dimensions fall two standard deviations on either side of the median. The D_{75} and D_{25} dimensions were chosen to provide data intermediate within the first standard deviation.

Table III is a tabulation of size values for substrate particles at the D_{50} and D_{20} passing size fraction increments. The values are derived from the gradation curves in Appendix A.

The D_{50} and D_{20} passing fractions were chosen to tabulate because: 1) the D_{50} is a median value and 2), the D_{20} passing value defines the division between coarse sand and gravel in the shaded

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TABLE
III
Comparison of D50 and D20 Sizes for Substrate Gravel by River

STANISLAUS			TUOLUMNE			MERCED		
River Mile	D50	D20	Riffle #	D50	D20	Riffle#	D50	D20
34.15	12	1.8	12	10.5	0.8	50	14	10.5
2M1	40	11	15	12	10.5	51	13	7
36	18	2	18	14	10	52	13	9
38	10	2	20	14	11	62	16	10.5
40.2	13	10	23D	11	3.5	64	11.3	4
42.2	11	2	28	11	10	65	11.3	5
43.2	11	1.8	30	11	6	71	12.5	7
44.2	11	0.8	36	11	3	Gall1	12	10
44.7	6	0.6	40	11	7	Gall2	12.5	8
45.2	11	1.15	43	12	10			
47	11	1.2	48	14	12			
47.3	11	8	50	10.5	2			
48.8	11	8	4A	12	8			
49.2	11	1.2	54	13.5	10.5			
49.4	12	6	7	11.5	6.5			
49.7	7	0.7	9	11.5	8			
50.9	11.5	2.2	A1	15	10			
51.4	12	10	A2	12.5	7			
51.9	13	10	Rudd1	15	12.5			
52.5	13	10.5	Rudd2	11.2	2.5			
53.3	11.5	7						
53.4	12	10						

area plotted on gradation curves in Appendix A. Additionally, the D_{20} value intersects the range of acceptable or suitable spawning gravel at 5 mm. A sample with a D_{20} passing value which does not exceed 5 mm falls out of the suitable range.

Table IV presents the mean values and variances for these size fractions. The non-parametric nature of the data (non-normal distribution and widely differing variances) preclude parametric hypothesis tests to determine whether significant differences in grain size distribution exist between each stream.

However, a review of the means indicates that the D_{20} passing size fraction appears appreciably smaller in the Stanislaus River. Otherwise, particle sizes at both size fractions appear equal in all streams. The smaller mean (4.91 mm) of the D_{20} passing fraction from the Stanislaus River indicates that riffles on that stream may be more sand-laden than the other rivers.

TABLE IV

Means and Variances of D50 and D20 Fractions

D50	Mean (mm)	Variance
Stanislaus	12.68	42.20
Tuolumne	12.21	2.22
Merced	12.24	2.13

D20	Mean (mm)	Variance
Stanislaus	4.91	16.36
Tuolumne	7.54	12.69
Merced	7.88	5.55

Table V tabulates riffles with a sand content which is greater than optimal for egg and alevin survival. This tabulation is derived from reading the gradation curves in Appendix A.

TABLE V

Sand-Laden Riffles

Stanislaus River River Mile	Tuolumne River Riffle Number
34.15	Rudd2
36.00	36
38.90	
42.20	
43.20	
45.20	
45.20	
49.20	
49.70	
50.90	

The plot of the gradation curves relative to the shaded area in Appendix A indicate the spawning suitability of each analyzed riffle. Each analyzed riffle is represented by three curves: the surface curve, the substrate curve, and the combined curve. To represent suitable spawning gravel, the three curves should fall within the shaded area. The plot of the combined curve is the most important indicator of suitability because it represents the entire composition of the gravel used by the salmon.

If the curves fall to the left of the shaded area at the D_{20} passing fraction, that is if the size of the fraction is five millimeters or less, the gravel may be considered sand-laden and therefore less than suitable for salmon spawning.

Sand-laden riffles on the Stanislaus and Tuolumne rivers are distributed downstream of a series of gravel pits. The influence of these pits on the sand content of the downstream riffles composition is not known. Nor is known the influence of bank erosion on gravel composition. The resolution of these issues should be addressed.

To restore the sand-laden riffles, two approaches may be taken: 1) ripping the riffles to release sand and 2) control of sand discharge into the stream above River Mile 50 on the Stanislaus River. Ripping is conventionally done with a bulldozer with ripper bars. Continuous maintenance will likely be necessary to keep these riffles suitable for spawning gravel.

SURFACE SAMPLING DATA ANALYSIS

Wolman counts were conducted simultaneously with bulk sampling for additional surface data. Appendix D presents plotted Wolman count curves. These curves indicate wide particle size variation. The curves also indicate that the surface size distribution of gravel in each riffle is roughly similar in each river. The shapes of the Wolman curves, with some exceptions, are roughly similar, indicating that surface distribution of particles by size is roughly equal on all rivers.

ANALYSIS OF SPAWNING GRAVEL AREA

The spawning areas presented in this assessment are not the total spawning area available to chinook salmon in the three rivers. As discussed previously, chinook salmon will likely spawn in other areas not included in these measurements. The preferred spawning area extends downstream from the head of the riffle to points where vegetative encroachment, stream flow velocity, or observed gravel dimension are insufficient to provide a preferred spawning area. Preferred spawning gravel is defined as gravel where flow velocity, water depth, and gravel composition are optimal for chinook salmon spawning. The area of each analyzed spawning riffle is presented in Tables VI, VII and VIII. Mean areas of the selected, preferred riffles ranged from

4445 square feet on the Merced River to 3571 square feet on the Stanislaus River. The equality of mean riffle areas may reflect hydrologic processes which preceded upstream dam construction.

River discharge, watershed area and morphology, underlying geology, and gradients are roughly the same in each river.

TABLE VI
Preferred Spawning Gravel Area
Stanislaus River

River Mile	Preferred Spawning Gravel Area (ft^2)	River Mile	Preferred Spawning Gravel Area (ft^2)
56.00	5500	45.10	6136
53.40	1800	45.00	1200
53.30	2750	44.70	8820
53.10	1296	44.60	7200
53.00	720	44.50	6300
52.60	300	44.30	800
52.50	5050	44.20	4180
51.90	11990	44.00	2800
51.80	240	43.80	7700
51.55	2500	43.70	1600
51.40	3980	43.20	3150
50.90	5250	43.00	3500
50.20	1600	42.60	3200
49.70	4785	42.20	6889
49.60	720	42.00	900
49.40	2070	40.40	540
49.30	2400	40.20	3780
49.20	8375	38.90	1800
49.10	3750	38.10	720
48.80	4272	38.00	4265
48.70	4500	37.50	2160
47.80	800	37.40	1800
47.40	9100	36.90	7200
47.30	6237	36.70	3600
47.10	2400	36.40	2700
47.00	6000	36.00	3655
46.80	6000	35.70	3600
46.70	800	35.60	1400
46.50	1200	35.50	2400
46.30	1800	35.00	3600
46.20	1500	34.20	8000
45.80	1200		
45.50	600	Area Total (ft^2):	232,120
45.20	5040	Mean Area (ft^2):	3571

TABLE VII Preferred Spawning Gravel Area Tuolumne River			
Riffle Number	Preferred Spawning Gravel Area (ft^2)	Riffle Number	Preferred Spawning Gravel Area (ft^2)
A2	1160	23C	1295
A7	5000	23D	1620
1A	30000	24	1664
2	18688	26	840
3B	4400	27	400
4A	6030	28	2970
6	4813	29	1716
7	11868	30A	2580
8A	3964	30B	5200
8B	4240	31	21000
9	3350	32	1750
10	5060	33	2500
11	4250	RUDD1	NM
12	1287	RUDD2	NM
13A	2115	36	2100
13B	4000	37	3250
13C	1200	38	2400
14	300	40	6400
15	880	43	5520
16	2500	45	1800
17A	4500	46	1200
17B	1500	48	5200
18	2560	50	4345
18B	600	53	1920
19	1500	54	2190
20	1400	56	
		Area Total (ft^2):	211,575
		Mean Area (ft^2):	3991 NM: Not Measured

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TABLE VIII Preferred Spawning Gravel Area Merced River			
Riffle Number	Preferred Spawning Gravel Area (ft^2)	Riffle Number	Preferred Spawning Gravel Area (ft^2)
5	4600	50A	2500
7	3960	51A	3980
12	4800	52	4000
17	3600	62	5390
22B	3200	64	4750
24	2835	65	5950
32	2550	71	2800
36	5625	GALL1	9450
42	3000	GALL2	7035
		Area Total (ft^2):	**80,025**
		Mean Area (ft^2):	**4445**

PART V: RIVER CONDITIONS

During the course of investigating the Stanislaus, Tuolumne, and Merced rivers, we observed significant conditions along each river which may affect salmon spawning habitat. These observations are included in this part.

VEGETATION ENCROACHMENT

Selected Tuolumne River riffle maps in Appendix E illustrate the vegetative encroachment on riffles. Maps of riffles 2, 6, 8A, 9, 10, 11, 13A, 13B, 23D, and 28 portray invasion of vegetation into the active stream channel. Vegetation along the river banks generally consists of trees, broad-leaf shrubs, and perennial aquatic grasses. This bank-side vegetation does not appear to affect riffles. However, vegetation in the active stream channel generally consists of mat-like grasses whose root systems thoroughly invade the riffle gravel. These mat-like grasses appear to trap sand and silt and create islands in the channel. They appear to degrade the quality of otherwise suitable spawning areas by preventing redd construction.

Vegetative encroachment may be the result of dam-impeded spring and early summer snow-melt runoff which historically flushed these river systems. Increased nutrient loading from agricultural runoff may promote vegetative growth.

COARSE GRAVEL DOWNSTREAM OF DAMS

On the Merced and Tuolumne rivers, the suitability of salmon spawning habitat is degraded by excessively coarse gravel and cobbles immediately downstream of the dams. Gradation curves in Appendix A for Tuolumne River Riffles A1, A2, and (marginally) 4A and for Merced Riffles 50, 51, 52, 62, and 64, generally fall out on the coarse-side of the shaded area which defines suitable salmon spawning gravel. Although coarse gravel is reasonably expected at the foothill/valley transition where these riffles are located, the altered hydraulic regime resulting from the construction of dams has eliminated sufficient fines from the rivers immediately below the dams. The altered hydraulic regime resulting from dam construction enhances the erosive and scouring capacity of the river at these points, thereby removing size fraction suitable for spawning.. The analyzed riffles on the reaches immediately downstream of the dams were the only areas which may support spawning. Entire stretches within these reaches are scoured, particularly on portions of the river underlain by bedrock. Where gravel exists, it is inappropriately large. Riffles A1, A7, and 3B illustrate the distribution of coarse gravels in the active channel.

ENGINEERED RIFFLES ON THE TUOLUMNE RIVER

Two sampled riffles, 1A and 2, on the Tuolumne River were constructed by Turlock and Modesto Irrigation Districts as mitigation for loss of spawning gravel caused by construction of upstream dams. These riffles are constructed to provide artificial habitat for chinook salmon spawning on a reach of river otherwise largely absent of preferred spawning gravel. Maps of these riffles are contained in Appendix E. The alternation of coarse and less coarse gravel provides a series of simulated spawning habitats: the alternation mimics the transition from coarse gravel to less coarse gravel at natural riffle-heads. Note encroachment of vegetation in Riffle 2 in Appendix E.

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CONVERSION FACTORS

Quantity	To Convert from Metric Unit	To Customary Unit	Multiply Metric Unit By	To Convert to Me Unit Multiply Customary Unit :
Length	millimetres (mm)	inches (in)	0.03937	25.4
	centimetres (cm) for snow depth	inches (in)	0.3937	2.54
	metres (m)	feet (ft)	3.2808	0.3048
	kilometres (km)	miles (mi)	0.62139	1.6093
Area	square millimetres (mm^2)	square inches (in^2)	0.00155	645.16
	square metres (m^2)	square feet (ft^2)	10.764	0.09290
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometres (km^2)	square miles (mi^2)	0.3861	2.590
Volume	litres (L)	gallons (gal)	0.26417	3.7854
	megalitres	million gallons (10^6 gal)	0.26417	3.7854
	cubic metres (m^3)	cubic feet (ft^3)	35.315	0.02831
	cubic metres (m^3)	cubic yards (yd^3)	1.308	0.76455
	cubic dekametres (dam^3)	acre-feet (ac-ft)	0.8107	1.2335
Flow	cubic metres per second (m^3/s)	cubic feet per second (ft^3/s)	35.315	0.028317
	litres per minute (L/min)	gallons per minute (gal/min)	0.26417	3.7854
	litres per day (L/day)	gallons per day (gal/day)	0.26417	3.7854
	megalitres per day (ML/day)	million gallons per day (mgd)	0.26417	3.7854
	cubic dekametres per day (dam^3/day)	acre-feet per day (ac-ft/day)	0.8107	1.2335
Mass	kilograms (kg)	pounds (lb)	2.2046	0.45359
	megagrams (Mg)	tons (short, 2,000 lb)	1.1023	0.90718
Velocity	metres per second (m/s)	feet per second (ft/s)	3.2808	0.3048
Power	kilowatts (kW)	horsepower (hp)	1.3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0.14505	6.8948
	kilopascals (kPa)	feet head of water	0.33456	2.989
Specific Capacity	litres per minute per metre drawdown	gallons per minute per foot drawdown	0.08052	12.419
Concentration	milligrams per litre (mg/L)	parts per million (ppm)	1.0	1.0
Electrical Conductivity	microsiemens per centimetre (uS/cm)	micromhos per centimetre	1.0	1.0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1.8 × °C)+32	(°F−32)/1.

C −1 0 4 7 5 1